EVALUATION OF CURRENT PILLAR DESIGN PRACTICE IN RAMAGUNDAM COAL BELT

A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology
in
Mining Engineering

by

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National Institute of Technology Rourkela – 769 008

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Under the Guidance of

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NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, **—Evaluation of Current Pillar Design Practice in Ramagundam Coal Belt** submitted by **Mr Basava Vishal Naidu, Roll No. 112MN0535** in partial fulfilment of the requirement for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

Date:

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ACKNOWLEDGEMENT

First and foremost, I express my profound gratitude and indebtedness to **Dr. M. K. Mishra**, Professor of Department of Mining Engineering for allowing me to carry on the present topic **—Evaluation of Current Pillar Design Practice in Ramagundam Coal belt** and later on for his inspiring guidance, constructive criticism and valuable suggestions throughout this project work. I am very much thankful to him for his able guidance and pain taking effort in improving my understanding of this project.

An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

At the last, my sincere thanks to all my friends who have patiently extended all sorts of helps for accomplishing this assignment.

Date: **Basava Vishal Naidu**

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CONTENTS

ABSTRACT

Bord and Pillar mining is the oldest and most popular mining method to extract coal from underground. It is simple, easy to operate and reasonably safe. The pillars form the natural support to the overburden roof and transfer the load to floor. In the process a large portion of the coal remain blocked for long period till depillaring is carried out. The underground coal mines in India predominantly follow the Bord and Pillar method of extraction. The stability of the roof and floor depends on the stability of the pillar. The pillar stability depends on its strength, nature of coal, presence of discontinuity, method of extraction, etc. In India DGMS guidelines govern the design of pillars whereas in other parts of world the pillar design is based on strength calculation of coal and other factors. Some of the approaches are given by Bieniawski, CIMFR, Obert – Duvall, Jaiswal – Shrivastava etc.

In this investigation an attempt has been made to investigate the current pillar design practice in one major coal belt of India vis-à-vis other approaches. The investigation was considered in terms of extraction percentage and safety factor for each design approaches. Pillar dimension has been optimised to determine the extraction ratio of a stable safety factor. 35 m square pillar was found to be stable with more than 2 % enhanced recovery at a depth of 270 m in comparison to the existing practice.

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CHAPTER 1

INTRODUCTION

Background of the Problem

Aim of the study

Methodology

Layout

INTRODUCTION

1.1 Background of the problem

Electricity is the key to development of human civilization as well as the source to achieve higher standard of modernization. Fossil fuels generate two - thirds of the world's electricity. Coal occupies the largest share and it will continue for foreseeable future. Coal is extracted by open cast and underground mining methods. Though open cast mining is currently practised widely, it has its own limitations whereas underground mining is being practised since decades. Among the various underground mining methods, Bord and Pillar method of working occupies major share. Though longwall mining is gaining importance for its multiple advantages yet Bord and pillar continues to be predominantly popular because of its simplicity and ease in operation. Pillars act as a natural support to the roof and transfer the overburden load to the floor. Thus, in this method, a significant amount of coal is locked in the pillars and unless depillaring is carried out, that amount of coal will be lost. However, in Indian coal mines Bord and pillar method is the most popular and is followed in majority of underground coal mines.

The design practice for pillars in Indian mines is primarily governed by DGMS guidelines. Literatures reflect that in other parts of the world, the design of the pillars is governed by mathematical approaches rather than fixed guidelines that India has. In mathematical approach, safety factor is the primary consideration for the stability and unstability of the pillar. The current investigation evaluates the applicability of mathematical approaches to one of the mines of Ramagundam, SCCL vis-à-vis DGMS approach.

1.2 Aim of the study

The aim of the investigation was to enhance the extraction percentage without compromising on the safety.

1.2.1 Specific Objectives

The aim is achieved by addressing the specific objectives as below:

- To predict the safety factor and extraction percentage for existing practice.
- To predict the safety factor by established approaches.
- To predict the safety factor by optimizing pillar dimensions.
- To predict the extraction percentage for the optimized pillar dimensions.

- To evaluate the applicability of a few design approaches as Bieniawski, CIMFR, Jaiswal-Shrivastava and Obert-Duvall.

1.3 Methodology

The aim and specific objectives were achieved by following a step by step specific process as outlined in the figure below.

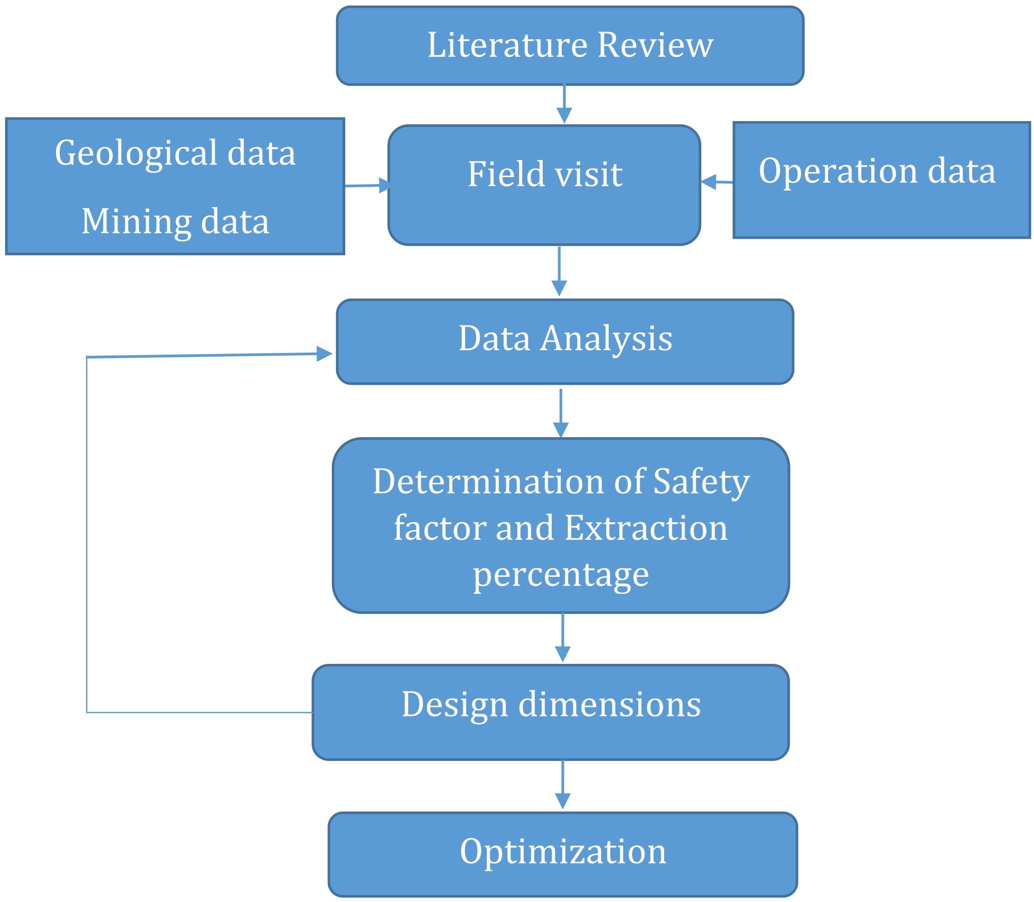

Fig 1.1: Flow chart of the methodology followed

1.4 Layout

The investigation report consists of five chapters. The first chapter shows the background, aim and objectives with the methodology followed. The second chapter deals in the literature review to understand the process and factors involved. The data collected are given in the next chapter. Chapter 4 discusses the results obtained in the investigation and their analyses followed by conclusion in next chapter.

CHAPTER 2

LITERATURE REVIEW

Bord and Pillar Working Method
Basic Principles of pillar design
Pillar strength Approach
Statutory Guidelines
National Status
Basics of Numerical Modelling

LITERATURE REVIEW

2.1 Bord and Pillar Working method (Figure 2.1)

This method is adopted for workings having seam characteristics such as

- thickness of more than 1.5m
- preferably free from stone or dirt bands
- moderate depth
- not gassy
- strong roof and floor that can stand for long period

Most of the coal seams in India satisfy the above the conditions and therefore bord and pillar method of mining has been commonly adopted in a large number of mines. The advantages of this method are:

Advantages:

- Comparatively great operational flexibility
- Relative freedom in the sequence of seam extraction
- Insensitivity to local and geological disturbances
- Low capital intensive
- Integrity of roof strata and surface

Disadvantages:

- Coal has to be left in the form of pillars to support the roof
- Productivity is low compared to opencast and longwall workings

A set of headings is driven in the dip-rise and level directions. This proves the thickness and gradient of the seam and gives an idea of the rate of gas emission, watery nature, roof condition and geological disturbances such as faults, dykes etc. Districts are opened from such set of headings. The manner of opening out districts depends upon:

1. Mode of entry into the seam, whether by incline or by a pit.
2. Type of transport system used for the districts.
3. Gradient of the seams.
4. Nature of coal, whether liable to spontaneous heating or not.

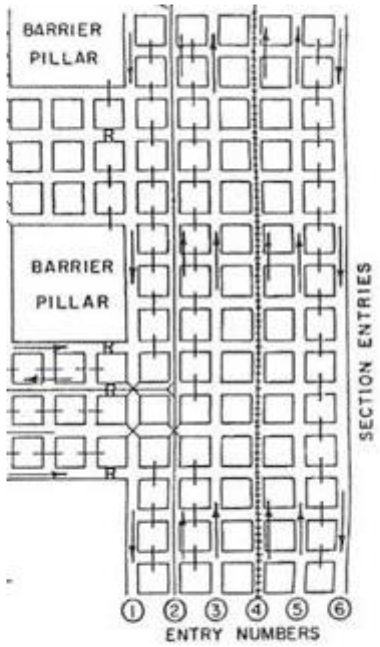

Fig 2.1: Schematic layout of typical Bord and Pillar working

2.2 Basic principles of pillar design

Pillar loading is of three types:

1. Preliminary loading: Loading immediately following excavation of opening
2. Subsequent loading/abutment pressures
3. Post mining loading

The classic method consisted of three steps:-

i. Estimating the pillar load using Tributary area theory
ii. Estimating the pillar strength using a pillar strength formula
iii. Calculating the pillar safety factor

2.2.1 Tributary area theory

According to this concept, a pillar takes the weight of overlying rock up to a distance of half the opening width surrounding it. In the figure, w_p is the width of the pillar and w_o is the width of the opening respectively, while L_p is the length of the pillar.

For square pillars,

$$w_p = L_p$$

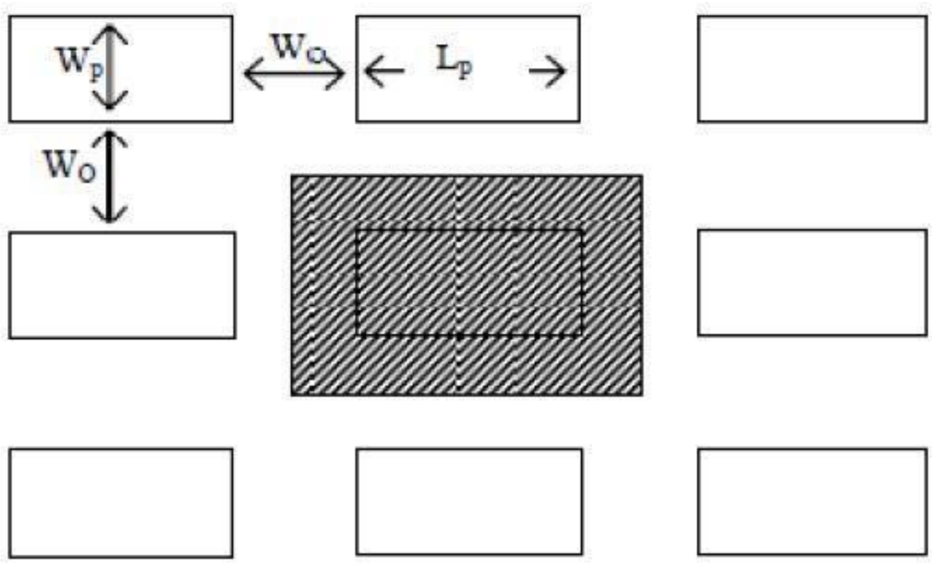

Fig 2.2: The tributary area pillar loading concept (after *Bieniawski*, 1984)

The load on the pillar,

$$F = (w_o + L_p) \times (w_o + w_p) \times \gamma \times g \times h$$

Where γg is the weight of the rock per unit volume, and h is the depth of mining. The stress on the pillar σ is:-

$$\sigma = F / \text{Area} = [(w_o + L_p) \times (w_o + w_p) \times \gamma \times g \times h]/(w_p \times L_p)$$

2.2.2 Pressure Arch theory

Before an opening is excavated, the underground stress distribution is uniform and the magnitude of vertical stress increases proportionally to the depth. But once an opening is made, the portion of the strata directly above the opening loses its original support and the stress equilibrium is disturbed. As a result, the load of the intermediate roof is transferred towards both sides of the opening, which are called abutments. The roof starts to sag under gravitational force. If the immediate roof strata are competent, the sag will stop before the roof collapses and the stresses around the openings will eventually reach a new equilibrium. However, in many cases, the immediate roofs of entries are not competent enough to sustain the changes of stress distribution and the interaction induced by mining. These may finally collapse into the opening if they are not sufficiently supported by some means.

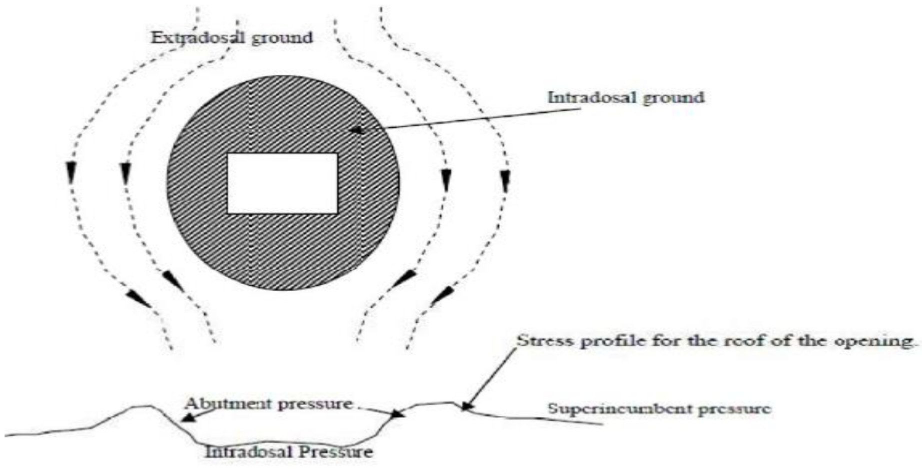

Fig 2.3: The Pressure arch theory (after *Bieniawski*, 1984)

2.2.3 Wilson's Approach

Wilson's theory of pillar design is credited with the introduction of the concept of confinement in pillar design. The higher the confinement is, the higher the pillar strength.

Applicability:

As soon as a pillar is formed, two zones develop:

(a) An outer yield zone and

(b) An inner elastic core.

The yield zone fails and cannot take any more loads, but it provides confinement to the inner core. Immediately after development, the highest stress is located at the boundary of yield and core zones. When loading increases such that the core is completely yielded, any additional loads will be transferred to adjacent pillars.

Strength of the core increases due to confining constraint due to the yield zone, given by the following relationship:

$$\sigma_1 = \sigma_c + \sigma_3 \tan\beta$$

where, σ_1 = stress at failure

σ_3 = confining stress offered by broken rock to the coal core

σ_c = Unconfined Compressive Strength

2.2.4 Determination of Pillar Strength

The strength of the pillar depends on various factors such as coal strength, roof and floor interaction, the size and shape of the pillars, depth, moisture content, geology of the local area, presence of geological influences etc.

2.2.4.1 Size and Shape effect on compressive strength of pillars

Size effect:

Compressive strength of coal depends on the distribution, type and condition of discontinuities. Smaller the specimen, less is the probability of containing discontinuities, resulting in greater strength.

The relationship between the size and the strength of the specimen can be generalized by the equation (Evans et al., 1961):

$$\sigma_c = k_1 . d^{-a}$$

Where σ_c is the UCS of cubical pillars, d is the side length of the specimen and k_1 and ɑ are constants. ɑ varies from 0.38 to 0.66 (Peng, 1978), with 0.5 being the average.

Critical size: Bieniawski (1969) performed a series of in-situ tests and found that for cubical specimens, the strength decreases with increasing specimen size and becomes constant when it reaches the critical specimen size of approximately 5 ft for coal. This implies that the strength of the critical sample may represent the strength of the in-situ coal pillar.

Another approach for extrapolating coal strengths from the laboratory strength to the in-situ ones can be expressed by the following equations (Hustrulid, 1976):

$$\sigma_c = K/36 \qquad \text{for } h > 36 \text{ in}$$

$$\sigma_c = K/\sqrt{a} \qquad \text{otherwise}$$

Where σ_c is the UCS of cubical specimens, a is the side length of the specimen and K is a site constant.

The pillars size is influenced by the following:

- Percentage extraction and depth of cover in the first workings or development.
- Strength of the coal: Seams with weak coal require large pillars.
- The nature of the floor and roof: A strong roof tends to crush the pillar edges whilst a soft floor predisposes it to creep and both calls for large pillars.
- Geological Considerations: In the vicinity of faults, large pillars are required. Dip and presence of water also influences the designing of pillars size.

Shape effect:

Coal strength is also found to depend on specimen geometry or shape effect i.e. the ratio of length to diameter of specimens (Evans et al., 1961; Obert and Duvall, 1967). Many formulas of average pillar strength have been proposed which can be categorised into groups:

$$\sigma_p = \sigma_c\,[A+B\,(w/h)]$$

$$\sigma_p = \sigma_c\,[w^a/h^b]$$

Where σ_p is the pillar strength and takes into account the shape effect, σ_c is the uniaxial compressive strength, w is the pillar width, h is the pillar height.

2.3 Pillar strength Approach

Numerous pillar strength formulas have been proposed, but five formulas are used most commonly (*Bieniawski*, 1984; *Peng*, 1986). Each formula specifies its own appropriate factor of safety. These are given below:

2.3.1 Obert - Duvall Approach (*Obert and Duvall, 1967)*

The formula is given as

$$\sigma_p = \sigma_c\,(0.778 + 0.222\,(w/h))$$

Where σ_p is pillar strength, σ_c is uniaxial compressive strength of a cubical specimen (w/h = 1), and w and h are pillar dimensions in meters.

This equation is valid for w/h ratios of 0.25 to 4.0, assuming gravity-loading conditions. Through back calculations from mining case histories and utilization of laboratory rock properties, safety factors of 2 to 4 were derived for short- and long-term pillar stability, respectively.

2.3.2 CIMFR Approach *(Deb and Verma, 2016)*

CIMFR developed a formula for pillar strength taking into account the pillar w/h ratio, the uniaxial compressive strength of the pillar, the height of seam and depth of cover.

$$\sigma_p = (0.27\times \sigma_c \times h^{-0.36}) + [(H/160)(w/h - 1)]$$

Where, σ_p = Pillar strength (MPa)

σ_c = Uniaxial compressive strength, UCS (MPa)

h = Working height or seam height (m)

H = Depth of cover (m)

w = Pillar width (m)

2.3.3 Bieniawski Approach *(Bieniawski 1968,1969)*

This approach is based on large-scale in situ tests on coal pillars. Extensive tests were conducted in South Africa during 1965–1973 by *Bieniawski*(1968, 1969), Wagner (1974), and *Bieniawski and van Heerden*(1975). *Wang et al.* (1977) conducted in the United States the largest test of all involving one full-sized coal pillar measuring 80 ft (24 m) in width. All these investigations examined the various pillar-strength formulas. The general normalized form of Bieniawski equation is

$$\sigma_p = \sigma_c (0.64 + 0.36 (w/h))$$

Where, σ_c is strength of the cubical specimen of critical seize or greater and σ_p is strength of the pillar.

2.3.4 Holland-Grady Approach *(Holland, 1964)*

The formula is given as

$$\sigma_p = k \sqrt{w}/h$$

Where, k = gaddy factor

w,h = pillar dimensions in in.,

σ_p = pillar strength in psi

Holland specified a saftery factor between 1.8 and 2.2 with a suggested value of 2. This equation is valid for w/h ratios of 2 to 8. Although popular in the 1970s, the Holland-Gaddy formula is no longer recommended because it was found to be overly conservative at higher ratios (> 5).

2.3.5 Salamon- Munro Approach *(Salamon and Munro, 1967)*

The formula is given as:

$$\text{Strength } (\sigma_p) = k\, h^a\, w^b$$

The constants for the above equation were derived from a statistical survey of data reflecting actual mining experience. In all, 125 case histories were used, of which 98 were standing pillars and 27 were failed pillars (collapsed at the time of the analysis). In deriving a pillar strength formula, it was assumed that those pillars that were still intact had safe dimensions, while the collapsed pillars were too small.

2.3.6 Jaiswal-Shrivastava *(Jaiswal and Shrivastava, 2009)*

The statistical expression of pillar strength as a function of w/h and σ_c has been established and is linearly dependent on w/h and non-linearly dependent on σ_c [10].

$$\text{Pillar Strength (MPa)} = \sigma_c^{0.66}\,[0.1514(w/h) + 0.2664]$$

An approach based on back-analysis was made against various failed/stable cases of coal pillars of Indian mines. The statistical expressions for estimation of pillar strength were developed by analyzing the results of the simulations carried out using a three – dimensional finite element model [10].

2.4 Statutory Guidelines

In India, the dimensions of pillars and the width and height of galleries are regulated by Govt of India i.e. DGMS vide its Regulation 99 of Coal Mines Regulation 1957 (Table 2.1 and 2.2). The width of galleries should not exceed 4.8 m and the height of the galleries should not exceed 3 m. For width of galleries ranging from 3 m to 4.8 m, the dimensions of pillars for various depths of working are given below:

Table 2.1: Gallery width with respect to pillar distance (centre to centre)

Depth of the seam from the surface	**Where the width of the galleries do not exceed**			
	3 m	3.6 m	4.2 m	4.8 m
	The distance between the centres of adjacent pillars shall not be less than (in m)			
Not exceeding 60 m	12	15	18	19.5
Between 60 -90 m	13.5	16.5	19.5	21
Between 90- 150 m	16.5	19.5	22.5	25.5
Between 150- 240 m	22.5	25.5	30.5	34.5
Between 240 -360 m	28.4	34	39.5	45
Exceeding 360 m	39	42	45	45

Percentage extraction in development at different depths is tabulated below:

Table 2.2: Percentage of extraction with respect to Gallery width

Depth of the seam from the surface	**Where the width of the galleries do not exceed**			
	3 m	3.6 m	4.2 m	4.8 m
	Percentage of Extraction (%)			
Not exceeding 60 m	43.7	42.2	41.2	43.17
Between 60 -90 m	39.53	39.8	38.4	40.5
Between 90- 150 m	33.06	33.5	33.8	34
Between 150- 240 m	24.8	26.2	25.6	25.9
Between 240 -360 m	9.95	19.7	20.1	20.2
Exceeding 360 m	14.8	16.4	17.8	19

2.5 National Status

Various researchers have worked on the current pillar design practices in Indian mines.
Nayak and Dalai (2007) observed that the safety factor of the pillar in CIMFR approach was 2.93 and extraction percentage to be 33 % in one of the mines of MCL [18].

Mohanty and Singh (2009) concluded that maximum and minimum safety factor in CIMFR approach was 3.1 and 2.54, maximum and minimum safety factor in Obert-Duvall approach was 2.72 and 1.651, maximum and minimum safety factor in Bieniawski approach was 3.737 and 2.322 in one of the mines in Talcher [16].

Pati (2011) observed that using DGMS specification for minimum pillar dimension for all approaches, safety factors were found to vary from 0.70 to 6.12, at different depths and at particular width of opening in one of the mines of MCL [17].

2.6 Basics of Numerical Modelling

Approach of numerical method is to divide the problem into small physical and mathematical components and then combine the all influence of the components to approximate the behaviour of the whole system. The series of full mathematical equations is formed in this process then solved approximately. Various numerical modelling technique have been developed and currently being used worldwide. The methods are categorized as continuum, discontinuum and hybrid continuum or discontinuum.

The continuum postulation implies that at all point in a problem region cannot be open or broken into pieces. All material points originally in the neighbourhood of a certain point in the problem region, remain in the same neighbourhood throughout the deformation. The continuum problem can be solved by three different methods:

- Finite Element Method (FEM)
- Finite Difference Method (FDM)
- Boundary Element Method (BEM)

2.6.1 FLAC 3D

FLAC3D is a three-dimensional explicit finite-difference program for engineering mechanics computation. The basis for this program is the well-established numerical formulation used by our two-dimensional program, *FLAC*. *FLAC3D* extends the analysis capability of *FLAC* into three dimensions, simulating the behaviour of three-dimensional structures built of soil, rock or other materials that undergo plastic flow when their yield limits are reached. Materials are represented by polyhedral elements within a three-dimensional grid that is adjusted by the user to fit the shape of the object to be modelled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to applied forces or boundary restraints. The material can yield and flow, and the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Lagrangian, calculation scheme and the mixed-discretization zoning technique used in *FLAC3D* ensure that plastic collapse and flow are modelled very accurately. Because no matrices are formed, large three-dimensional calculations can be made without excessive memory requirements.

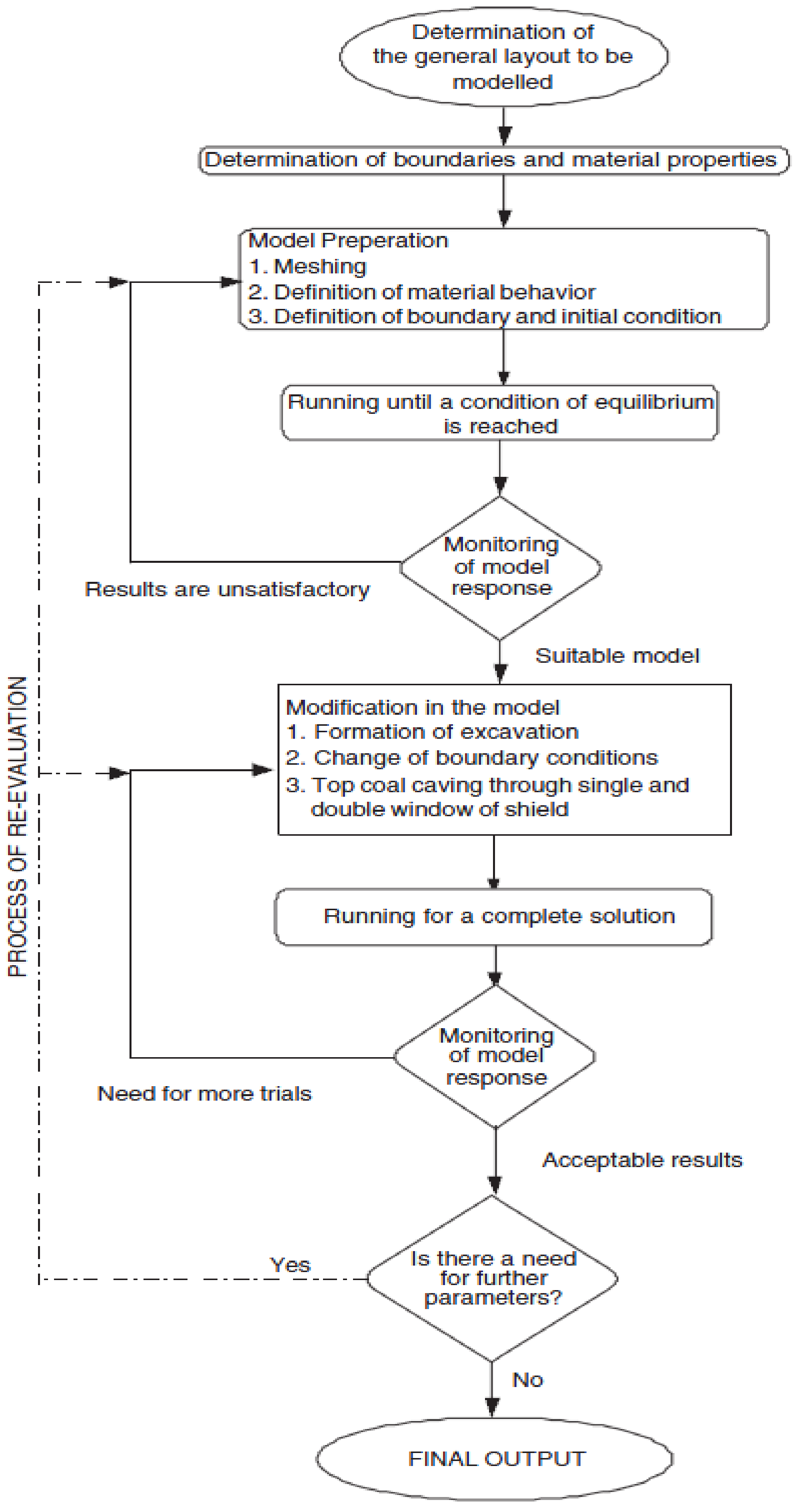

Fig 2.5 A general flowsheet of modelling procedure (Yasitli, 2002; Unver and Yasitli, 2002; Itasca, 1997).

CHAPTER 3

DATA COLLECTION

DATA COLLECTION

3.1 Data Collection

The goal and specific objectives were achieved by collecting field data as well as lab test data of the samples. The data collected included:

- Name and location of mine
- Coal seam Name
- Depth of coal seam and coal seam thickness
- Type of workings
- Geology
- UCS of coal, roof and floor
- Length and width of pillars, and length of opening spans
- Mining sequence
- Proposed pillar width
- Density of coal, roof and floor
- Young's modulus

3.2 Sample collection

The samples were collected from seam that was investigated. They were then placed in plastic bags to protect them from moisture and atmosphere gases, so that proper condition of sample could be maintained for laboratory testing. During the transportation of the samples they were kept in wooden boxes. Wooden boxes are usually preferred during the transporting of the coal samples because they protect the samples from sunlight. Sometimes there are chances for the sample to catch fire due to the heat of the sunlight. The wooden boxes also protect the sample from rainfall, hence maintaining the in-situ conditions during sample testing.

3.3 General Description of Mine

Geology

Ramagundam coalbelt is located on the western margin of NNW-SSE trending Pranhita Godavari Valley, situated on the Precambrian platform. The Godavari Valley extends over 470 km in strike length from Eluru on the east coast of Andhra Pradesh in the SE through the state of Telangana in the central parts up to Boregaon of Maharashtra in the NW. It is a 'Crevice' type of platform rift zone containing 4,000 m to 5,000 m fluviatile sediments of Early Permian to Early Cretaceous. It is considered the largest single Gondwana basin belt in India. Seven to ten coals of 1m to 22m thickness are present in the Barakar Formation located along the western margin and at some places on the eastern margin of the valley. Intercalated carbonaceous horizons are located in the Late Permian Raniganj Formation [14].

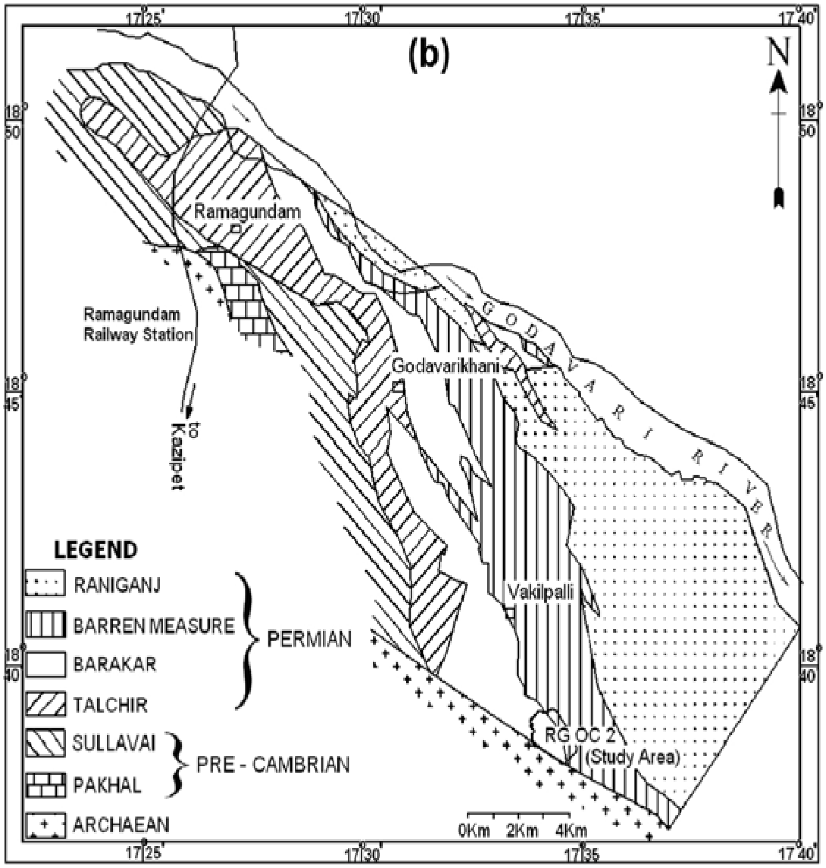

Fig 3.1: Geological Map of Ramagundam Coal belt (after *Bhaskar et al, 2015)*

Location

Vakilpalli Mine is one of the underground-mechanized mines of S.C.C.L. and this mine is an extension block of GDK9 Incline which was annexed into OCP1 Mine by constructing water dams between these blocks. And also this block is separated by a 45m up-throw fault into two blocks, i.e. Vakilpally Block and Jallaram block which was annexed into GDK10 Incline. The Vakilpalli Block is entered through a pair of long tunnels. The direction and average dip of the seams is N82^{0}E and 1 in 8.5 respectively.

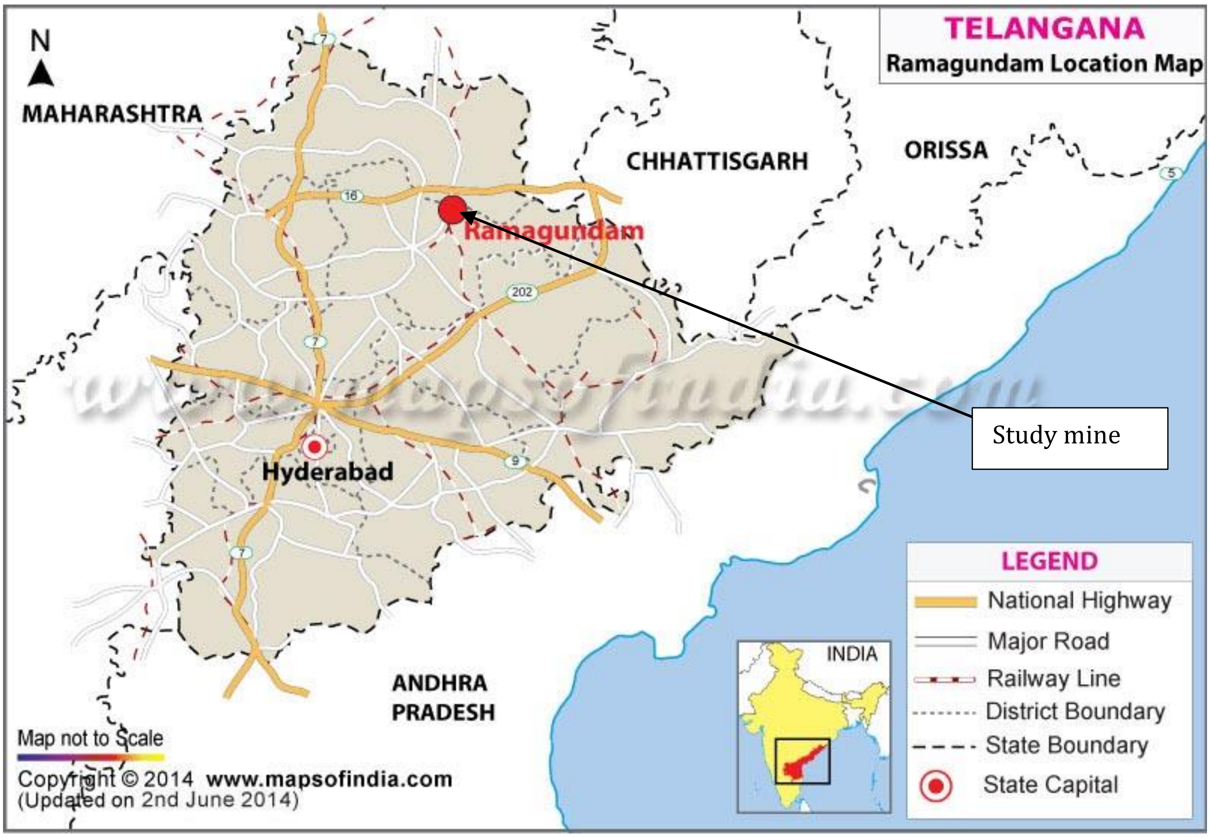

Fig 3.2: Location of the mine (http://www.mapsofindia.com/)

Status of existing seams and working

The vakilpalli block is having four seams namely No. 1 Seam, No. 2 Seam, No. 3 Seam and No. 4 Seam in descending order. The tunnels and air shaft have touched all the four seams.

No. 1 Seam: The extraction in No. 1 Seam is completed by Longwall retreating method and remaining workings were sectionalized. No.1 Seam of VKP Block-A is 5.0 to 6.5m thick. This includes two clay bands-top one with 0.6 to 0.8m thick and middle one with 0.3m thick. It is being worked along middle section with 2.8 to 3.0m height and includes middle clay at roof horizon. There is 2.2m coal and 0.6m clay in immediate roof and then massive sandstone. The RMR value of coal roof is about 43.65 and the roof is classified as "Class III A-FAIR.
(The Long wall unit is shifted to RK New Tech mine of Srirampur Area from No. 1 seam.)

No. 2 Seam: A single gallery of about 577 m is driven and the seam is having clay in the roof horizon and workability is yet to be decided.

No. 3B seam: The No. 3B seam is not in operation as there is no extractable thickness in the proposed project area.

No. 3A seam: The thickness of the seam is varying from 0.3m to 2.0m over the area and not in extractable thickness over a large area of the proposed project

No. 3 Seam: In No. 3 Seam south side development is completed and extraction in BG 5 panel is under progress The RMR value of coal roof is about 51.65 and the roof is classified as "Class III B-FAIR"**.**

No. 4 Seam: In No. 4 Seam south side development is completed and extraction in No. SSI Panel by hydraulic sand stowing is under progress and also north development is under progress.

The RMR value of roof is about 54.00 and the roof is classified as "Class III –FAIR".

CHAPTER 4

RESULTS AND DISCUSSIONS

RESULTS AND DISCUSSIONS

4.1 Introduction

The aim of the investigation was to enhance the production of the mine. The aim was achieved first by evaluating the current existing production, then changing the pillar dimension and optimizing it with respect to production and safety factor.

The investigation is carried out in two stages:

1. Determining the strength of the coal
2. Determining the safety factor

4.2 Strength of the coal

Coal blocks of the seam were collected and cored samples were tested in the laboratory as per for geotechnical parameters. The testing was carried out as per ASTM D2938 – 95 (2002). The average values are reported here:

The average UCS value of the sample after 3 tests is 19.82 MPa

The average tensile strength value of the sample after 3 tests is 1.985 MPa.

4.3 Safety Factor Analysis

The current pillar design practised as per the DGMS guidelines fix the pillar size for an overburden of 240-360 m and gallery with of 4.2 m as 40 m. There were unstable cases observed and all the pillars exhibited stable behaviour. The extraction percentage was 17.46% whereas the worldwide average is 45 to 50 %

The safety factors for current pillar of 40 m width and 3 m height is obtained using various approaches have been calculated.

1. **Obert-Duvall Approach**

   The average stress on the pillar (σ_{avg}) = 11.81 MPa

   The strength of the pillar (σ_p) = σ_1 (0.778 + 0.222 (w/h))

   = 74 MPa

   Factor of Safety = σ_p / σ_{avg} = 6.26

2. **Bieniwaski Approach**

   The strength of the pillar (σ_p) = σ_1 (0.64 + 0.36 (w/h))

   = 107.82 MPa

   Factor of Safety = σ_p / σ_{avg} = 9.13

3. **CIMFR Approach**

The strength of the pillar (σ_p) = $(0.27\times \sigma_c \times h^{-0.36}) + [(H/160)(w/h - 1)]$

$= 33.08$ MPa

Factor of Safety = $\sigma_p / \sigma_{avg} = 3.0$

4. **Jaiswal - Shrivastava Approach**

The strength of the pillar (σ_p) = $\sigma_c^{0.66}\,[0.1514(w/h) + 0.2664]$

$= 16.4$ MPa

Factor of Safety = $\sigma_p / \sigma_{avg} = 1.45$

The results have been tabulated below.

Table 4.1: Safety factors for 40 m pillar using various approaches

S.No.	Approach	Safety Factor
1.	Obert-Duvall	6.26
2.	Bieniawski	9.13
3.	CIMFR	3
4.	Jaiswal-Shrivastava	1.45

From the table, the factor of safety calculated from CIMFR method is 3. A typical coal pillar in the gallery has a life span of 3-4 years. So the recommended safety factor of coal pillars should be around 1.5 to 2. So this gives the possibility of decreasing the safety factor which in return would increase the extraction percentage without compromising with safety factor.

4.4 Extraction Percentage

The percentage of extraction for current pillar of 40 m width and 3 m height is calculated as below:

Percentage of extraction (R %) = $[1-(w_p/w_p+w_e)^2] \times 100$

$= (1- (40/44)^2) \times 100$

$= 17.35\%$

Thus the extraction percentage was found to be 17.35 %.

As per Coal Mines Regulation 1957, if depth of the seam from the surface lies between 240-360 m and the width of the galleries do not exceed 4.2 m, the extraction ratio should be 20.1 %. But the extraction ratio in this case is found to be 17.35% whereas in developed countries it is more than 40 %. Therefore the extraction percentage has to be enhanced by optimizing pillar dimensions and gallery width.

4.5 Numerical Modelling Results

Numerical Modelling was done to estimate the average stress, maximum stress and deformation in the pillar. Finite Difference Method was used for the study and the software was FLAC 3D. A sample code for the development of pillar in FLAC 3D has been shown in Appendix-1.

4.5.1 Average vertical stress on the 40 m pillar

The 3-D modelling of the pillar of 40 m width and 3 m height has been done and the properties attributed were:

Floor:

Material = Sandstone

Thickness = 10 m

Young's Modulus = 2.6 GPa

Poisson's ratio = 0.25

Density = 2262 kg/m^3

Coal seam:

Material = Coal

Thickness = 3 m

Young's Modulus = 1.42 GPa

Poisson's ratio = 0.25

Density = 1335 kg/m^3

Roof:

1) **Sandstone**

   Thickness = 8 m

   Young's Modulus = 2.4 GPa

   Poisson's ratio = 0.25

   Density = 2250 kg/m^3

2) **Coal**

Thickness = 8 m

Young's Modulus = 2.6 GPa

Poisson's ratio = 0.25

Density = 1690 kg/m^3

3) Sandstone

Thickness = 22 m

Young's Modulus = 2.75 GPa

Poisson's ratio = 0.25

Density = 2210 kg/m^3

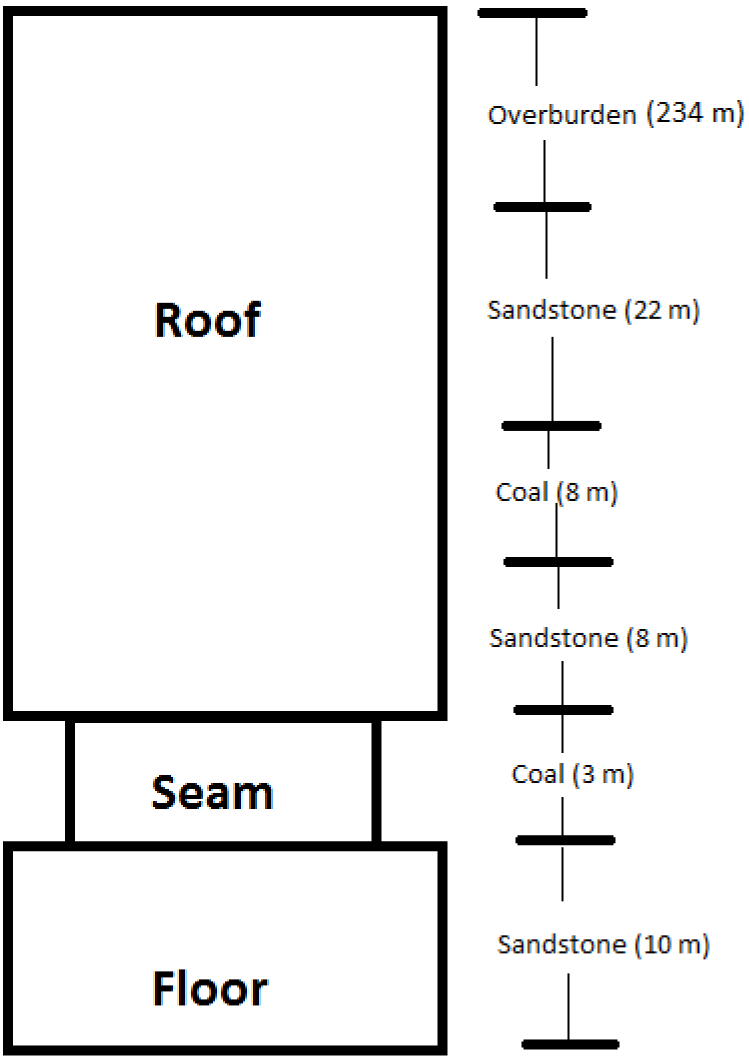

Fig 4.1: Typical Layout of the model

The average stress of the square pillar (40 m × 40 m), height 3 m was found to be 10.28 MPa for a depth of 272. 755 m.

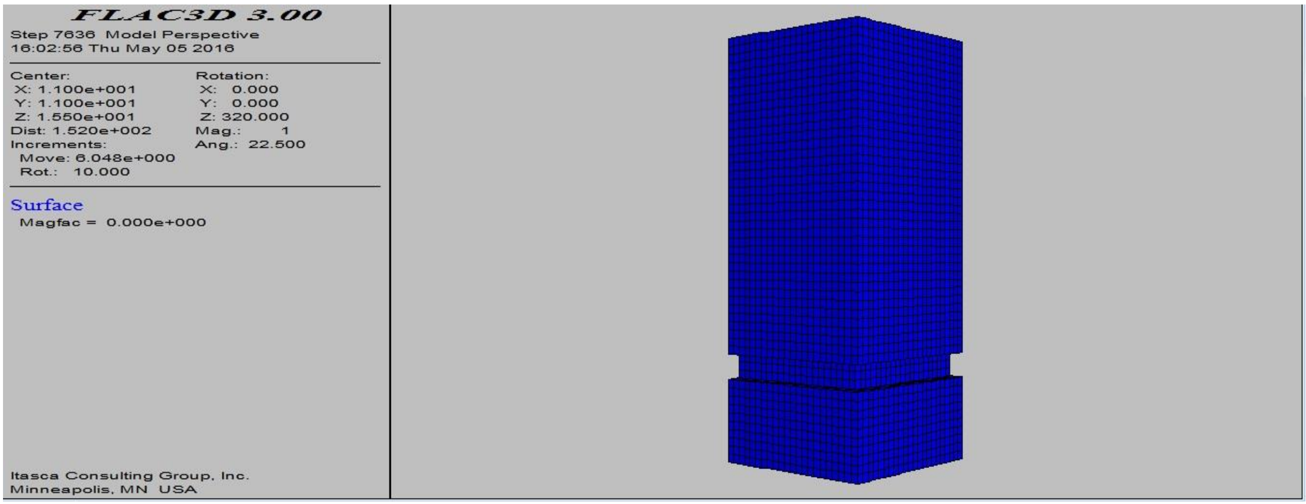

Fig 4.2: Modelled pillar of 40 m width

CIMFR Approach:

Strength of the pillar (σ_p) = 33.08 MPa

Stress on the pillar (σ_{avg}) = 10.28 MPa

Factor of Safety = σ_p / σ_{avg} = 3.2

Jaiswal-Shrivastava Approach:

Strength of the pillar (σ_p) = 16.4 MPa

Stress on the pillar (σ_{avg}) = 10.28 MPa

Factor of Safety = σ_p / σ_{avg} = 1.6

Thus the numerical factor of safety using CIMFR approach was found to be 3.2 and using Jaiswal-Shrivastava approach was found to be 1.6.

4.5.2 Stress Contour plot of 40 m pillar

From the stress contour plot, maximum stress on the 40 m pillar was found to be at the centre and is about 15.72 MPa.

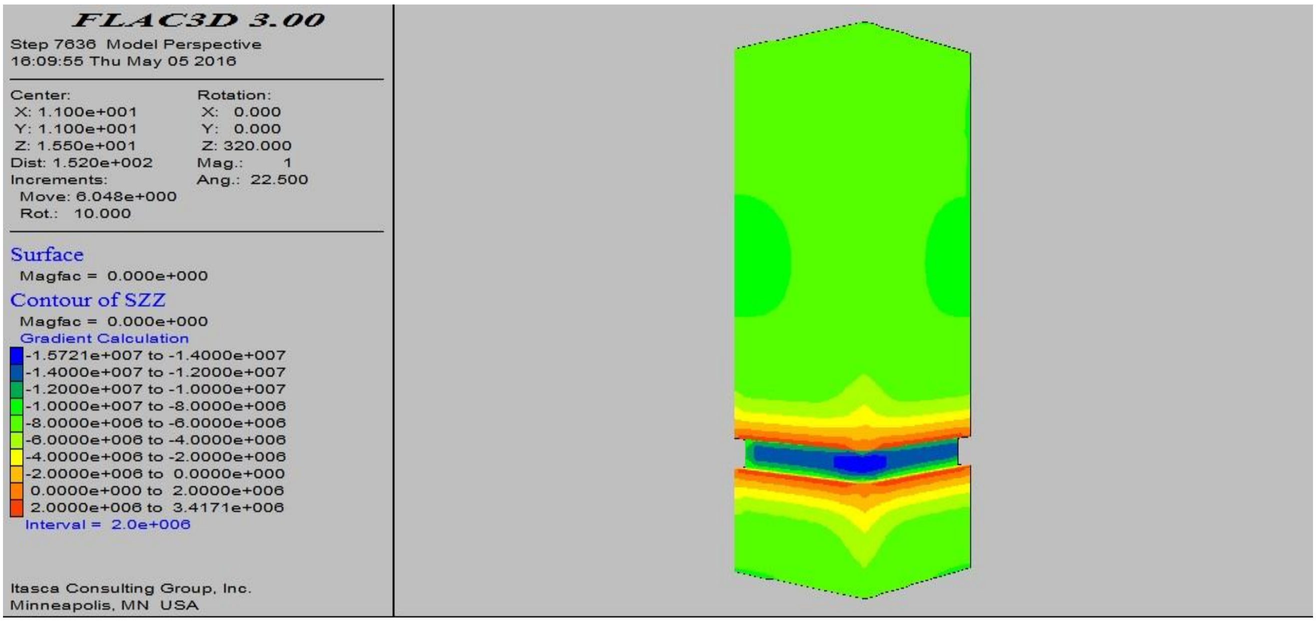

Fig 4.3: Stress Contour plot of 40 m pillar

4.5.3 Deformation Contour plot of 40m pillar

From the deformation contour plot, the maximum strain percentage in the 40 m pillar was found to be 0.91 %.

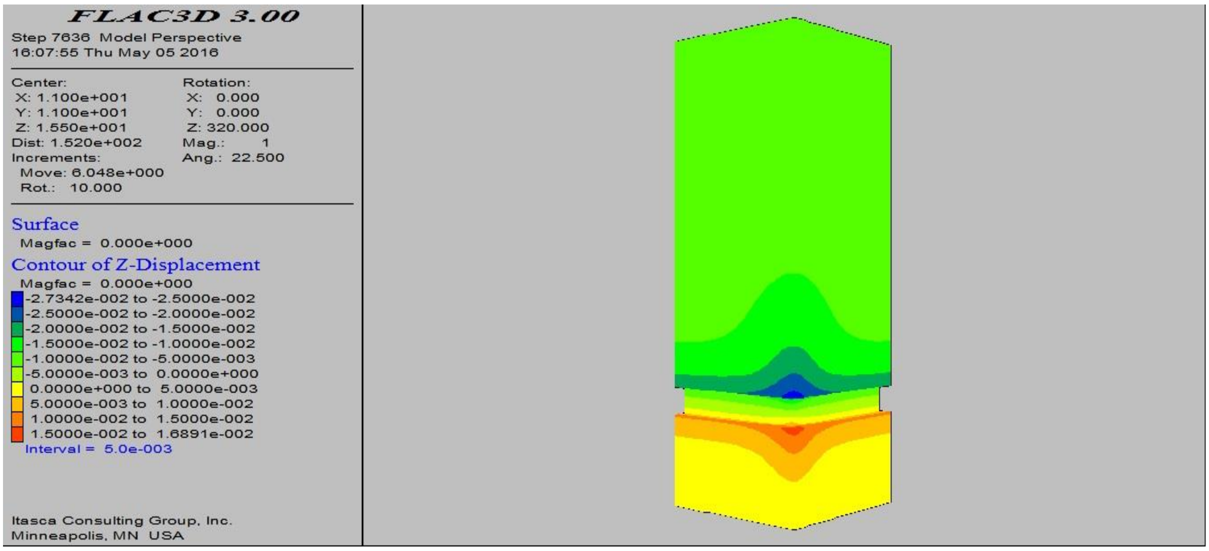

Fig 4.4: Deformation Contour plot of 40 m pillar

4.6 Optimization of pillar dimensions

Using CIMFR pillar strength approach and tributary area theory for determining the average stress on the pillar, pillar sizes have been determined for varying safety factors ranging from 2 to 3 and then safety factors using Jaiswal-Shrivastava pillar strength equation has been used for those pillar sizes. The results have been tabulated below.

Table 4.2: CIMFR and Jaiswal-Shrivastava Safety factors for various Pillar width to height (w/h)

w/h	CIMFR Safety Factor	Jaiswal-Shrivastava Safety Factor
9.37	2	0.984
10.19	2.2	1.078
11	2.4	1.17
11.31	2.6	1.26
12.32	2.8	1.36
13.42	3	1.45

The results have been plotted as shown in fig 4.5

Fig 4.5: Variation of safety factor with respect to Pillar Width to Height (w/h)

From figure 4.5, the following conclusions were drawn:

- For the same pillar width to height, CIMFR safety factor is higher when compared to Jaiswal-Shrivastava safety factor.

- Also, assuming the seam thickness is uniform, as the pillar width increases from 28 m to 40.2 m, the CIMFR safety factor has increased from 2 to 3 whereas Jaiswal-Shrivastava safety factor has increased from 0.984 to 1.45.
- It can also be observed that with an increase of 43.22 % in pillar width to height the CIMFR safety factor increases by 50 % whereas Jaiswal-Shrivastava safety factor increases by 47.36 %.

Thus at Jaiswal-Shrivastava safety factor of 1.25, the pillar width is 35m and this was assumed to be the optimum width.

4.6.1 Safety factor Analysis

Safety factors for 35 m pillar have been estimated using both empirical and numerical approach and the results are tabulated below.

Table 4.3 Safety factors using empirical and numerical approaches

Safety factor	**CIMFR**	**Jaiswal-Shrivastava**	**Obert-Duvall**	**Bieniwaski**
Empirical	2.5	1.25	5.74	8.25
Numerical	2.74	1.37	6.28	9.03

Thus by reducing the pillar size to 35 m, the numerical CIMFR safety factor was found to be 2.74 and numerical Jaiswal-Shrivastava safety factor was found to be 1.37 which are sufficient for safe extraction.

4.6.2 Extraction Percentage

The percentage of extraction for 35 m pillar has been calculated and compared with the current extraction percentage as shown in figure 4.6.

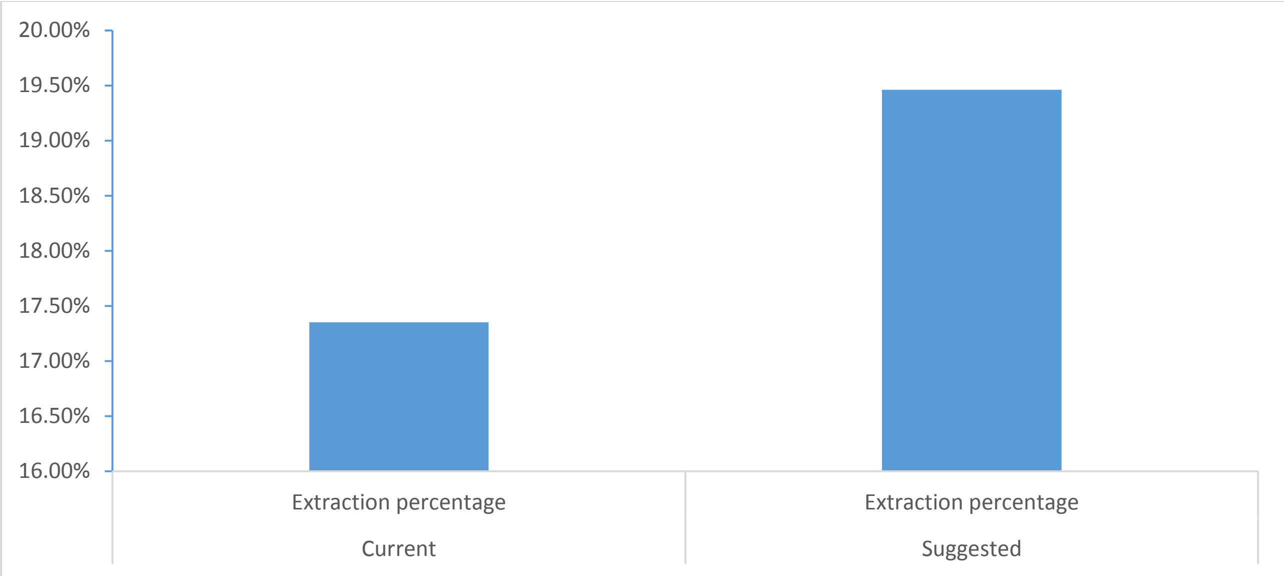

Fig 4.6: Comparison of Extraction percentages

Bord and pillar mining consists of three major parts: main dip, panel gallery and face. The life of the main dip is more or less equal to the life of the mine, the life of the panel gallery is about two years and for the face the life is short. So it assumed that the safety factor the face is 1.2 and for the main dip it is about 1.5. Thus for a safety factor of 1.2, Jaiswal-Shrivastava approach has exhibited a percentage extraction of 19.46% and for the same configuration applied to CIMFR approach, the percentage extraction was much higher. Thus instead of 40 m, if 35 m is taken as the pillar width the extraction percentage would be enhanced by about 2 %.

4.6.3 Stress contour plot of 35 m pillar

From the stress contour plot, maximum stress on the 35 m pillar was found to be at the centre and is about 17.83 MPa.

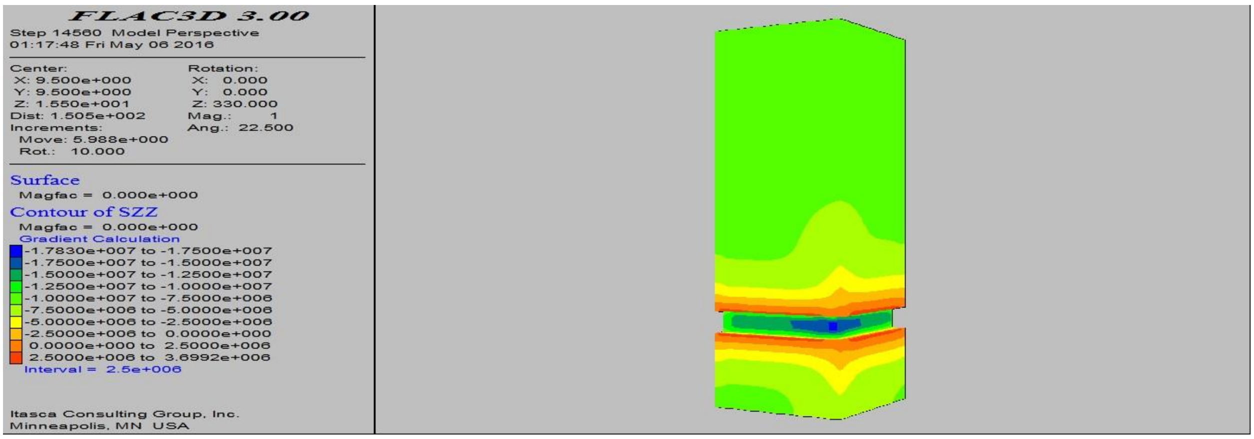

Fig 4.7: Stress Contour plot of 35 m pillar

Thus by reducing the pillar size from 40 m to 35 m, the maximum stress on the pillar would be increased from 15.72 MPa to 17.83 MPa which is less than the UCS of the coal (19.82 MPa).

4.6.4 Deformation Contour plot of 35 m pillar

From the deformation contour plot, the maximum strain percentage in the 40 m pillar was found to be 1.13 %.

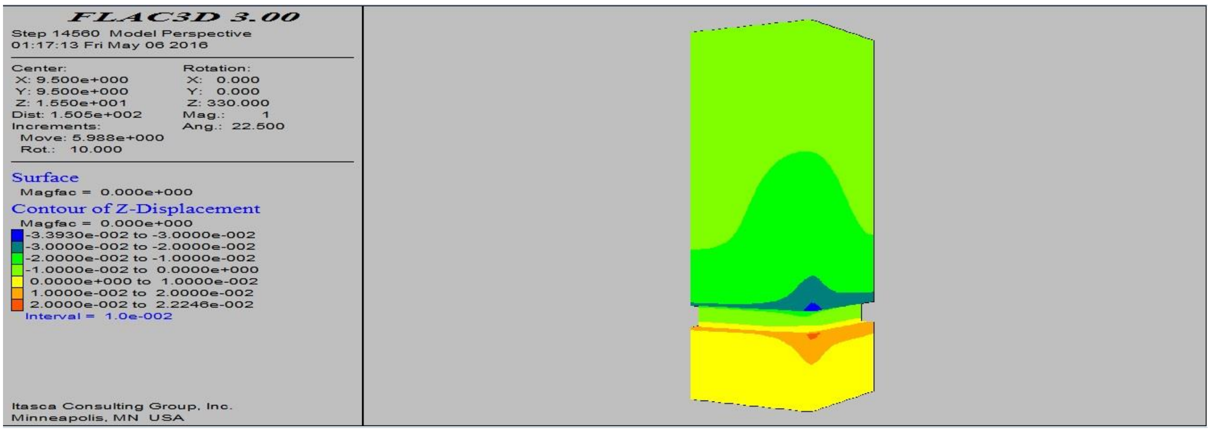

Fig 4.8: Deformation Contour plot of 35 m pillar

Thus by reducing the pillar size from 40 m to 35 m, the maximum strain percentage on the pillar would be increased from 0.91% to 1.13% which lies between 1 to 2%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Case study Mine:

- Ramagundam coalbelt is located on the western margin of NNW-SSE trending Pranhita Godavari Valley, situated on the Precambrian platform. The coal is classified as a medium hard rock.
- The average UCS of the samples was found to be 19.82 MPa and the average tensile strength of the samples was found to be 1.985 MPa.
- Bord and Pillar method of mining with DGMS guidelines are followed with square size pillars. The gallery width and height of working did not change throughout the mine and safety factor was evaluated by varying other geotechnical parameters.

Current Existing Practice:

- Various approaches such as CIMFR, Obert-Duvall, Bieniawski, Jaiswal - Shrivastava were used in estimating safety factor with varying pillar dimensions.
- For 40m pillar width, the maximum and minimum safety factors are 9.13 as in Bieniawski approach and 1.45 as in Jaiswal- Shrivastava approach respectively.
- The percentage of extraction for existing pillar width (40 m) is calculated to be 17.35 %.

Optimized pillar dimensions:

To achieve maximum extraction percentage the pillar dimensions has been optimized to 35m.

- For 35m pillar width, the maximum and minimum safety factors are 8.25 as in Bieniawski approach and 1.25 as in Jaiswal - Shrivastava approach respectively.
- The extraction percentage for 35m pillar width is 19.46 % and thus has been improved by more than 2 %. Maximum percentage extraction can be achieved by further optimizing gallery width.
- Maximum stress induced over the pillar has been estimated using FLAC 3D and following conclusions were drawn:
    - **i.** For a pillar size of 40 m, the maximum stress developed in the pillar was 15.72 MPa.
    - **ii.** For a pillar size of 35 m, the maximum stress developed in the pillar was 17.83 MPa.

- Deformation in the pillar has been estimated using FLAC 3D and following conclusions were drawn:
  i. For a pillar size of 40 m, the maximum strain percentage was found to be 0.91 %.
  ii. For a pillar size of 35 m, the maximum strain percentage was found to be 1.13 %.

5.2 Recommendation

In this investigation a few aspects of pillar design such as seam thickness, depth of the seam, density of the overburden are taken into account to find the safety factor and extraction percentage. However, there are various factors such as roof pressure, effect of discontinuities, the horizontal and vertical stresses that affect the pillar strength. So it is strongly recommended that the more parameters may be taken into consideration in future.

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APPENDIX-1

Sample Numerical Modelling Program for 40 m pillar

```
new

;Floor sst 10m
;Gallery in x-direction
gen zone brick p0(0,0,-10) p1(20,0,-10) p2(0,2,-10) p3(0,0,0) size 20 2 10 ratio 1,1,1
;Junction
gen zone brick p0(20,0,-10) p1(22,0,-10) p2(20,2,-10) p3(20,0,0) size 2 2 10 ratio 1,1,1
;Gallery in y-direction
gen zone brick p0(20,2,-10) p1(22,2,-10) p2(20,22,-10) p3(20,2,0) size 2 20 10 ratio 1,1,1
;Pillar
gen zone brick p0(0,2,-10) p1(20,2,-10) p2(0,22,-10) p3(0,2,0) size 20 20 10 ratio 1,1,1

;Coal seam 3m
;Gallery in x-direction
gen zone brick p0(0,0,0) p1(20,0,0) p2(0,2,0) p3(0,0,3) size 20 2 3 ratio 1,1,1
;Junction
gen zone brick p0(20,0,0) p1(22,0,0) p2(20,2,0) p3(20,0,3) size 2 2 3 ratio 1,1,1
;Gallery in y-direction
gen zone brick p0(20,2,0) p1(22,2,0) p2(20,22,0) p3(20,2,3) size 2 20 3 ratio 1,1,1
;Pillar
gen zone brick p0(0,2,0) p1(20,2,0) p2(0,22,0) p3(0,2,3) size 20 20 3 ratio 1,1,1

;Roof sst 8m
;Gallery in x-direction
gen zone brick p0(0,0,3) p1(20,0,3) p2(0,2,3) p3(0,0,11) size 20 2 8 ratio 1,1,1
;Junction
gen zone brick p0(20,0,3) p1(22,0,3) p2(20,2,3) p3(20,0,11) size 2 2 8 ratio 1,1,1
;Gallery in y-direction
gen zone brick p0(20,2,3) p1(22,2,3) p2(20,22,3) p3(20,2,11) size 2 20 8 ratio 1,1,1
;Pillar
gen zone brick p0(0,2,3) p1(20,2,3) p2(0,22,3) p3(0,2,11) size 20 20 8 ratio 1,1,1
```

```
;Roof coal 8m
;Gallery in x-direction
gen zone brick p0(0,0,11) p1(20,0,11) p2(0,2,11) p3(0,0,19) size 20 2 8 ratio 1,1,1
;Junction
gen zone brick p0(20,0,11) p1(22,0,11) p2(20,2,11) p3(20,0,19) size 2 2 8 ratio 1,1,1
;Gallery in y-direction
gen zone brick p0(20,2,11) p1(22,2,11) p2(20,22,11) p3(20,2,19) size 2 20 8 ratio 1,1,1
;Pillar
gen zone brick p0(0,2,11) p1(20,2,11) p2(0,22,11) p3(0,2,19) size 20 20 8 ratio 1,1,1

;roof sandstone 22m
;Gallery in x-direction
gen zone brick p0(0,0,19) p1(20,0,19) p2(0,2,19) p3(0,0,41) size 20 2 22 ratio 1,1,1
;Junction
gen zone brick p0(20,0,19) p1(22,0,19) p2(20,2,19) p3(20,0,41) size 2 2 22 ratio 1,1,1
;Gallery in y-direction
gen zone brick p0(20,2,19) p1(22,2,19) p2(20,22,19) p3(20,2,41) size 2 20 22 ratio 1,1,1
;Pillar
gen zone brick p0(0,2,19) p1(20,2,19) p2(0,22,19) p3(0,2,41) size 20 20 22 ratio 1,1,1

model elastic
;floor 10m
prop bulk 1.73e9 shear 1.04e9 density 2262 range z= -10,0
;E= 2.6GPa
;poisson's Ratio = 0.25

;coal seam
prop bulk 0.947e9 shear 0.57e9 density 1335 range z= 0,3
;E= 1.42GPa
;poisson's Ratio = 0.25

;sandstone 8m
prop bulk 1.6e9 shear 0.96e9 density 2250 range z= 3,11
;E= 2.4GPa
```

```
;poisson's Ratio = 0.25

;coal 8m
prop bulk 1.73e9 shear 1.04e9 density 1690 range z= 11,19
;E= 2.6GPa
;poisson's Ratio = 0.25

;sandstone 22m
prop bulk 1.83e9 shear 1.1e9 density 2210 range z= 19,41
;E= 2.75GPa
;poisson's Ratio = 0.25

;boundary conditions
fix x range x -0.1, 0.1
fix x range x 21.9, 22.1

fix y range y -0.1, 0.1
fix y range y 21.9, 22.1

fix z range z -9.9, -10.13
;insitu stress
set gravity 0 0 -9.81
;sxx=syy=2.4+0.01h
;h= 272.755
;szz=0.025h

ini sxx= -5.87e6 grad 0,0,0.01e6
ini syy= -5.87e6 grad 0,0,0.01e6
 ini szz= -8.675e6 grad 0,0,0.025e6
;trunkated overburden load for 233.755 m
apply szz= -7.7065e6 range z 40.9, 41.1
solve
save sym_insitu.sav
hist unbal
```